Overlooked model uncertainties may misinform forest management strategies

Victor, Jérôme, Isabelle, and more?

Abstract: Forests play a major role in mitigating climate change, but increasing threats to forests from climate change have heightened the importance of managing these systems. Robust forecasts of forest composition with increasing climate change are critical to this aim, but are currently highly variable. To help guide management in the face of this variability and understand where we can most rapidly reduce uncertainty through improved models, we compare over XX ecological models and climate scenarios in forecasts for forests across Europe. Our approach considers a gradient of more mechanistic ('process-based') to correlative models of species distributions to find that uncertainty in ecological models can drive more variation than vastly different climate scenarios (e.g., SSP2 vs. SSP5), but also areas with relatively consistent projections [give overview of these and say that this could reduce uncertainty in how to manage for these areas]. [Maybe something on using existing range data leads to more pessimistic forecasts?] Our results highlight a new way to approach ecological forecasting that better identifies areas of higher certainty and, conversely, the areas where managers will need more diversified approaches and where more ecological study may be most useful.

Main

Forests are key to pursuing climate change mitigation policies and achieving carbon neutrality[1,2]. Yet, forests are increasingly under pressure. In Europe, temperatures are rising twice as fast as the global average[3], and unprecedented pulses of tree mortality have been reported in the last decade[4]. As a result, some European forests are becoming net CO_2 sources[5,6], due to decreased growth[5,7], larger burned areas[8,9], and increased pest- and drought-induced dieback[6,10,11]. Forest managers are facing unprecedented challenges, as they must address current threats while also promoting long-term adaptation to climate change. In this context of high uncertainty, better guidance is needed to implement successful strategies.

Given the diversity of predictive ecological models, the challenge of providing practical insights for forest management is even greater. Different models, ranging from correlative to more mechanistic approaches, may provide highly divergent projections[12–15]. While it remains unclear under which conditions one approach is more reliable than another[16], most forecasting studies still rely on a limited set of models[17–20]. We thus often lack a comprehensive understanding of what drives differences between projections[21]. Given the urgency of climate change, we must incorporate this diversity and merge across ecological and climatological models to provide a complete picture of both the threats and opportunities for forests.

Gaining a better understanding of where uncertainties originate and how they relate is crucial to identify opportunities to address policy-relevant questions[22]. Species shifts are predicted to have major impacts on timber production and on the forest economic sector[18,19]. Forest managers need to know whether the current species will be able to tolerate future climate conditions, whether they can rely on its natural regeneration, or whether they should capitalize on new species opportunities. If the main driver of variation across projections is the different ecological models, even more than different global emissions scenarios, it becomes critical to

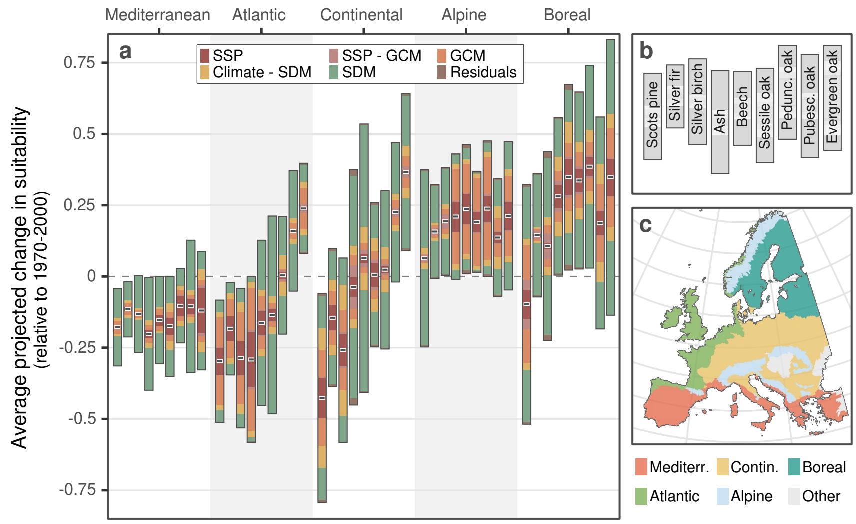

Figure 1

encompass the full range of models. Failing to do so could lead to overly confident predictions about which species will or will not be able to survive in future climates, ultimately leading to counterproductive or even detrimental forest management decisions.

To understand the level of confidence we can place in predictions requires a framework that account for all the various components of climatological and biological uncertainties, including socio-economic scenarios, global climate models, ecological models, down to the species level. To this aim, we combined over 1,500 projections of forest tree species distributions, incorporating a wide range of models, from more mechanistic ('process-based') to correlative models. Fully accounting for our current level of knowledge about future climate states and species functioning allows us to quantify the contribution of each component to the total variation across projections. This approach represents a significant advancement over previous studies, which overlooked large portions of uncertainty, and will lead to better informed decision-making to improve the resilience of forests.

Results and discussion

Our dataset included 9 tree species, both deciduous and coniferous, adapted to diverse climatic conditions across Europe. We simulated their suitability from 1970 to 2100, at a 0.1° spatial resolution, using a diverse set of ecological models spanning different hypotheses and calibration methods. For future projections, we used 10 different climate simulations, based on 2 forcing scenarios and 5 global climate models with different climate sensitivities.

Across species, ecological models drive more variation than vastly different climate scenarios. They consistently represent the major source of uncertainty across major European biomes (explaining between 42.9% and 63.9% of the variation between projections), with the exception of the Alpine biome. At the species-level, the differences between ecological models is also the main source of uncertainty for all the species considered here, and represents between 40% and 62% of the total uncertainty on average. One of the striking example is the climatic suitability change of sessile oak in the Atlantic region, where this species represents an important cultural and economic value, and for which more than 80% of the uncertainty in climate change impact projections was due to variations among ecological models.

Failing to account for a broad range of ecological models bias our level of confidence in them. Considering only correlative models would have misled to an overestimation of the contribution of climate projections (forcing scenarios, climate models, and their two-way interaction) to the total projection uncertainty in all regions, except the Mediterranean. In particular, divergence

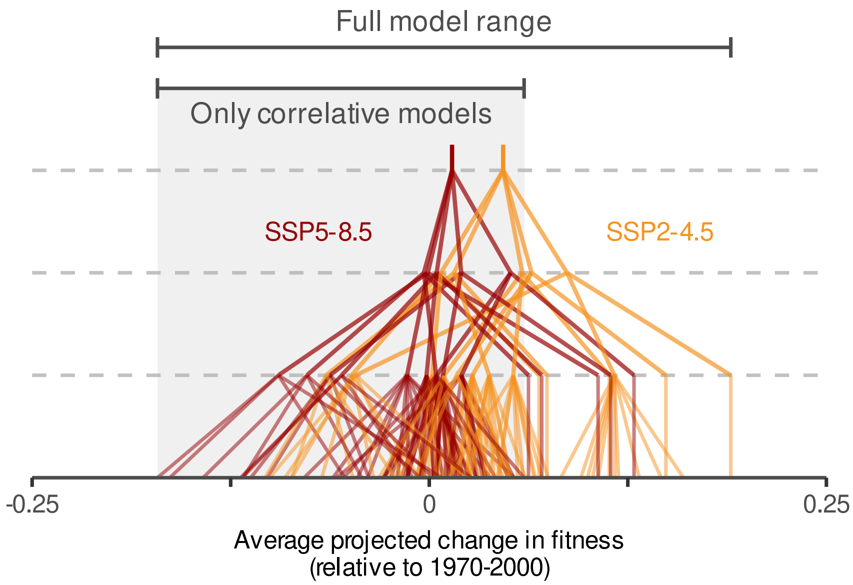

Figure 2: Temporary figure

between climate models would have appeared to contribute as much as ecological models to projection uncertainty (on average, 36.6% and 37.5%, respectively). By accounting for more diverse ecological models, as done in our study, the uncertainty introduced by different ecological models (51.0% on average) is greater than that introduced by climate models (19.9% on average) for all the species. One of the key challenges for reducing uncertainty remains at the biological and ecological levels, even before considering the broad variations across future climate projections.

Our results also revealed that the divergent projections between ecological models followed a regular pattern. Models (correlative or mechanistic) calibrated using current species range data consistently projected stronger decrease in climatic suitability for all species than models calibrated using other data (e.g. experimental). predict greater extinctions at the southern edge of species ranges greater extinctions at the warmer limits (generally southern) These discrepancies between models can significantly alter country-level projections, and impact national strategies derived from them. In Germany for example, beech showed an average suitability decrease of -0.04 (±0.09) in 2090 when considering only models entirely calibrated with current species distribution data, whereas... Distribution data may not capture the full climatic niche of a species, underestimating the range of conditions where it could survive[23,24]. Relying on a narrow set of models—especially derived from the same calibration process (too technical?)—undermines the robustness of projections!

Comparing diverse models enable to identify areas with relatively consistent projections that differ in terms of future climate risks and levers of action to address them. Around the Mediterranean Basin, the models consistently predict less favorable climatic conditions for the species we considered here. In areas where most species are threatened, forest managers may consider introducing new species, more drought-tolerant. In the Atlantic margin, the suitability of most species is also projected to decrease, except for the two Mediterranean species (pubescent and evergreen oaks). In some areas, evergreen oak has already replaced beech[25]. Mechanistic model projections are less pessimistic for deciduous oaks and beech in France, suggesting that some better-adapted populations could survive if the existing standing genetic variation is maintained and promoted by forest managers[26]. An other lever of action, practices: reduce forest density. Continental: exhibit less clear trends, notable low agreement among ecological models, as well as the mountainous regions at the transition between Mediterranean and Continental/Atlantic climates (Pyrenees, Massif Central, Balkans). Boreal biomes in Scandinavian and Baltic countries are projected to get an overall increase of climatic suitability. These are mostly dominated by two conifers species, favoured by commercial forest management Thanks to a more favourable

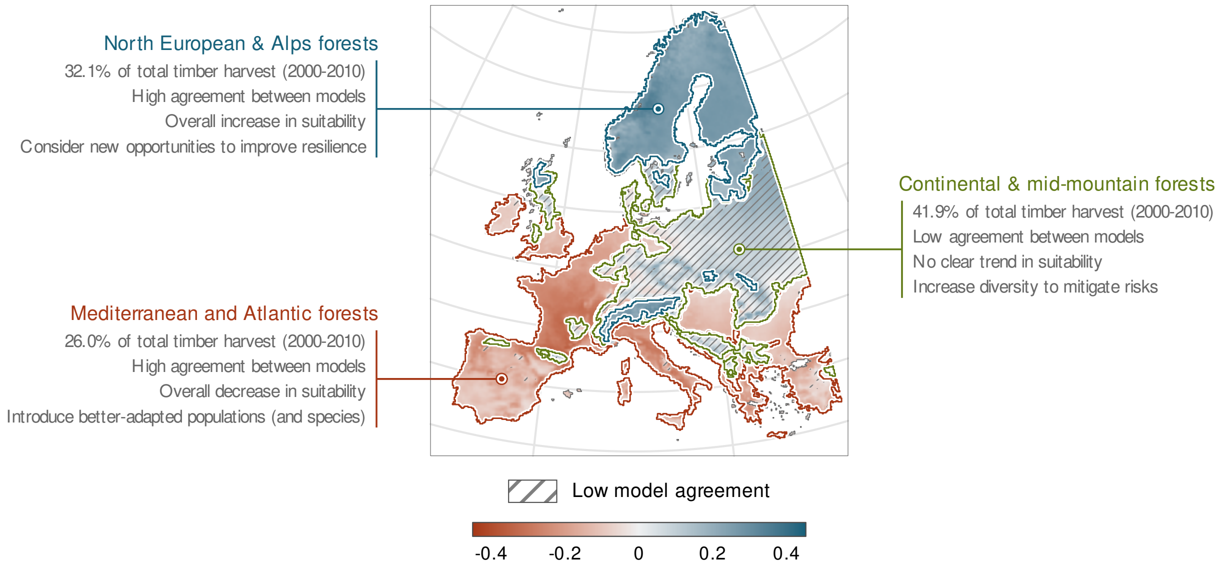

Figure 3: Temporary figure

climate and an extended growing season, temperate deciduous species can become more competitive at the northern margin of their range[27]. Lever of action: convert pure coniferous stands into mixed forest in order to increase their resilience[28]

Looking ahead: a call to action for the scientific community...

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